Comparison of RBE-weighted doses for different ion types in various tissue type combinations

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Introduction: The advantage of particle therapy is the inverse depth profile of the ions compared to conventional X-ray irradiation with a higher dose to the tumor region as compared to the surrounding normal tissue. For particle therapy the application of different ion types offer different physical and biological advantages. The purpose of this study is to assess the advantages of ions interesting for particle therapy, i.e. carbon (^{12}C), helium (^{4}He) and protons (^{1}H) for the particular treatment cases of radioresistant tumors and radiosensitive normal tissue, commonly parametrized by the ratio of the parameters α and β from the linear-quadratic (LQ) model with $\alpha/\beta = 2\,$Gy in the tumor region (T) and 10 Gy in the normal tissue (N), and vice versa.

Methods: A treatment planning analysis based on idealized target geometries was performed using the treatment planning software TRiP98 [1]. For the prediction of the relative biological effectiveness (RBE) that is required for biological optimization in treatment planning the Local Effect Model (LEM IV) was used [2]. To compare the three ion types the peak-to-entrance ratio (PER) was determined for the physical dose ($\mathrm{PER_{PHYS}}$), the RBE ($\mathrm{PER_{RBE}}$) and the RBE-weighted dose ($\mathrm{PER_{BIO}}$) resulting for different dose-levels, field configurations and tissue types. The peak position value, i.e. dose or RBE, is determined in the center of a 50 mm spread out Bragg peak (SOBP) and the entrance channel (EC) position value at 20 mm proximal from the SOBP.

Results: Figure 1 shows that the advantages of the ions, expressed by a high $\mathrm{PER_{BIO}}$, depend on the physical and biological properties and the interplay of both [3]. In the case of protons the consideration of a variable RBE instead of the clinically applied generic RBE of 1.1 indicates an increased $\mathrm{PER_{BIO}}$ due to an increased $\mathrm{PER_{RBE}}$ for the analyzed configuration. The blue line at a $\mathrm{PER_{RBE}}$ of 1.0 in fig.1 refers to a generic RBE of 1.1 for protons and marks the typical range of the $\mathrm{PER_{PHYS}}$ due to the depth modulation method [4]. Carbon ions show the largest variation of the $\mathrm{PER_{RBE}}$ with tissue type and dose and a benefit for radioresistant tumor types due to their higher LET. Helium ions show an intermediate $\mathrm{PER_{PHYS}}$ and $\mathrm{PER_{RBE}}$ for the α/β-ratio combination of 2_T,10_N. In contrast, for the α/β-ratio combination of 10_T,2_N the three ion types show similar $\mathrm{PER_{BIO}}$, thus indicating no ion type and dose dependence for this tissue type combination.

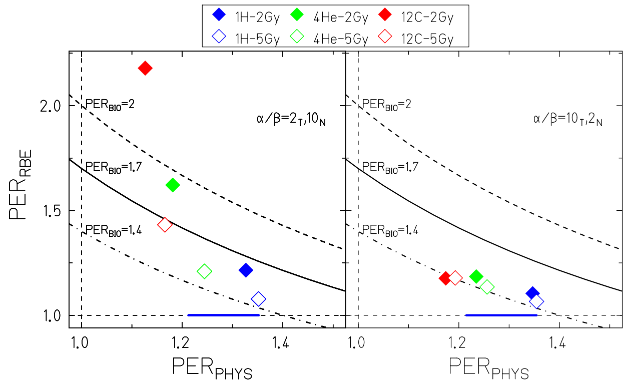

Figure 1: $\mathrm{PER_{RBE}}$ versus $\mathrm{PER_{PHYS}}$ in the case of a 1-field irradiation for protons (blue), helium (green) and carbon (red) at two different optimized RBE-weighted doses of 2 Gy (RBE) (closed symbols) and 5 Gy (RBE) (open symbols), respectively. Left: α/β-ratio combination of 2_T,10_N. Right: α/β-ratio combination of 10_T,2_N. Lines of a constant $\mathrm{PER_{BIO}}$ are added to guide the eye.

Conclusion: The study demonstrated that there is no unique choice concerning the optimal ion for radiotherapy. The expected therapeutic advantage strongly depends on biological as well as physical factors in combination with the treatment field configuration. Protons show a favourable physical depth dose profile compared to helium and carbon ions and are superior especially for radiosensitive tumors. Carbon ions are characterized by a high $\mathrm{PER_{RBE}}$ which is particularly pronounced at lower doses and for radioresistant tumors and are most beneficial in a single field treatment. Helium ions gain from both, the $\mathrm{PER_{PHYS}}$ and $\mathrm{PER_{RBE}}$ and favour of an intermediate $\mathrm{PER_{BIO}}$. Further, for the tissue type combinations with an α/β-ratio of 10_T,2_N the ion type and dose dependence for the case of a 1-field irradiation is negligible since the $\mathrm{PER_{RBE}}$ of helium and carbon ions is dumped and eventually similar to that of protons which seems rather independent on the tissue type combination.

References:

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